

US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002

RESEARCH STATUS OF IEC EXPERIMENTS AT NASA MARSHALL

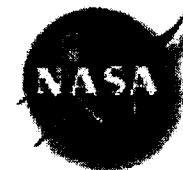
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NASA MSFC, PRC/TD40, HUNTSVILLE, AL

IVANA HRBUD, ERC, INC., NASA MSFC GROUP, HUNTSVILLE, AL



PRESENTATION OUTLINE



US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002 US-JAPAN IEC WORKSHOP 2002

- * IEC HISTORY AT PRC-NASA MSFC**
- * EXPERIMENTAL APPARATUS**
- * IEC PLASMA IMAGES**
- * DIAGNOSTICS**
- * RESULTS**
- * 3RD US-JAPANESE EXCHANGE/IEC WORKSHOP**



IEC HISTORY AT PRC



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*** 1997**

- ❖ Preliminary studies and discussions with UIUC

*** 1998**

- ❖ SBIR-Phase I, NPL Associates & UIUC

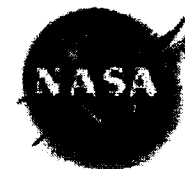
*** 1999**

- ❖ SBIR-Phase II, NPL Associates, UIUC.
- ❖ Dr. Jon Nadler (UIUC) and Ms. Chantelle Hurst (Purdue University) join PRC through SFFP.
- ❖ UIUC loans IEC experiment to PRC for initial operation and design template for PRC's IEC experimental program.
- ❖ Submitted CDDF proposal.
- ❖ Design and procurement of 2-foot vacuum chamber.



Propulsion Research Center

IEC HISTORY AT PRC



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*** 2000**

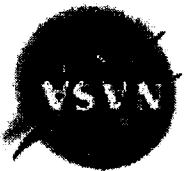
- ❖ CDDF approved for IEC propulsion research.
- ❖ Design of PRC vacuum chamber, procurement of all major components and build-up of laboratory facility.
- ❖ Identified grid manufacturing techniques and conducted grid fabrication experiments.
- ❖ Design of pulse forming network for pulsed, high-power operation.
- ❖ Ms. Chantelle Hurst (Purdue University) joins PRC as Accompanying Faculty Student.
- ❖ PRC's IEC experiment generates plasma with Ar, He, and N₂.

*** 2001**

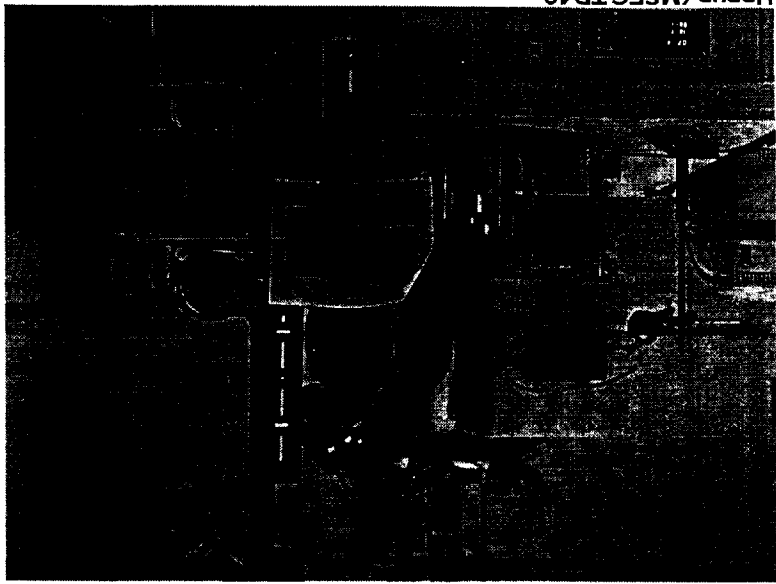
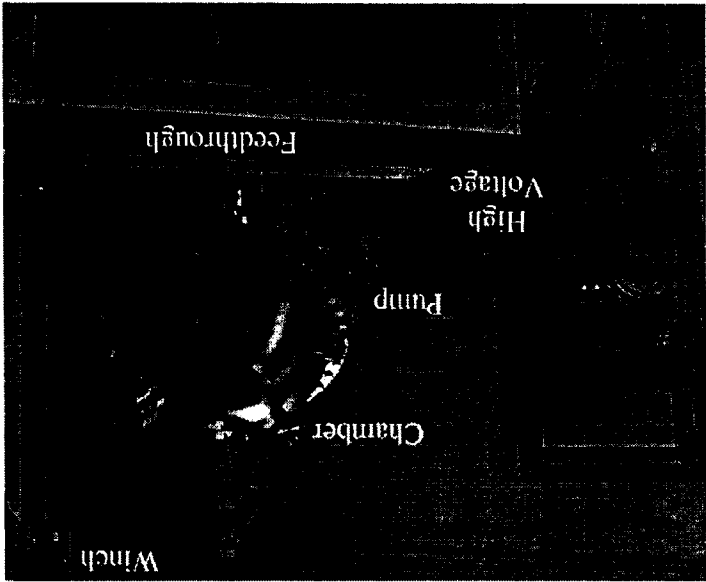
- ❖ Organized and hosted US-Japanese Exchange and IEC Workshop (March) introducing NASA Marshall to IEC community.
- ❖ Set-up of all major diagnostics and IEC plasma with H₂ (safety certification).
- ❖ Ms. Chantelle Hurst (Purdue University) joins as USRP.
- ❖ IEC plasma with Deuterium



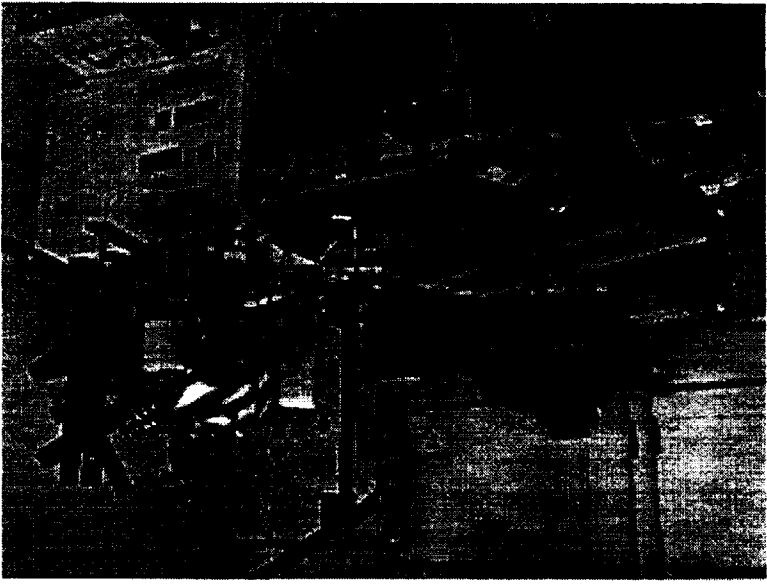
APPARATUS EVOLVEMENT



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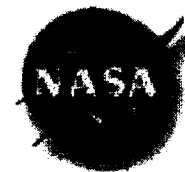


IVANA HRBUD/MSFC-TD40



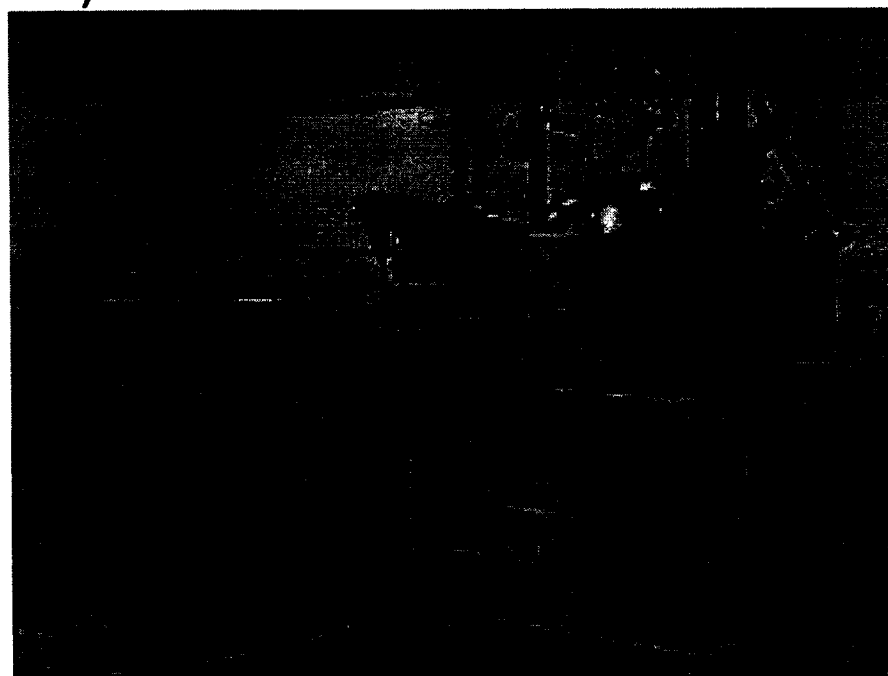


TEST APPARATUS-WINTER '02



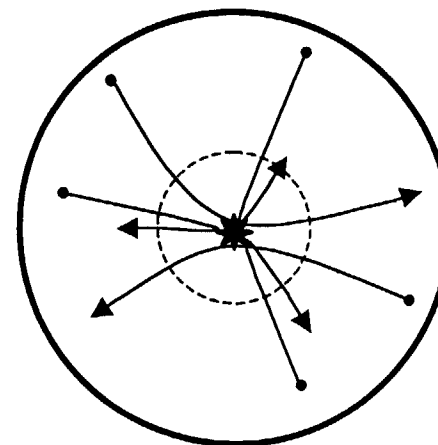
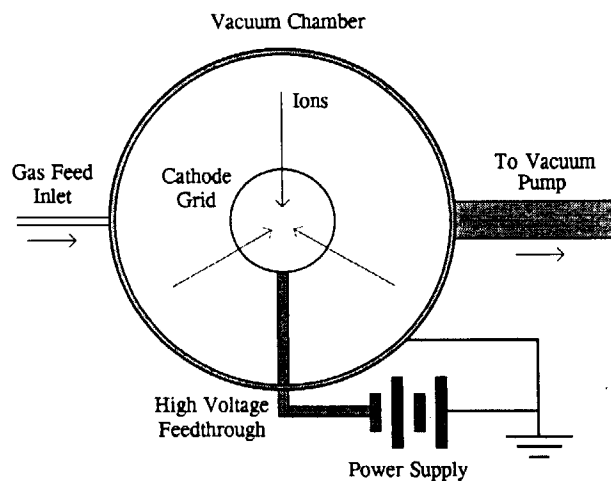
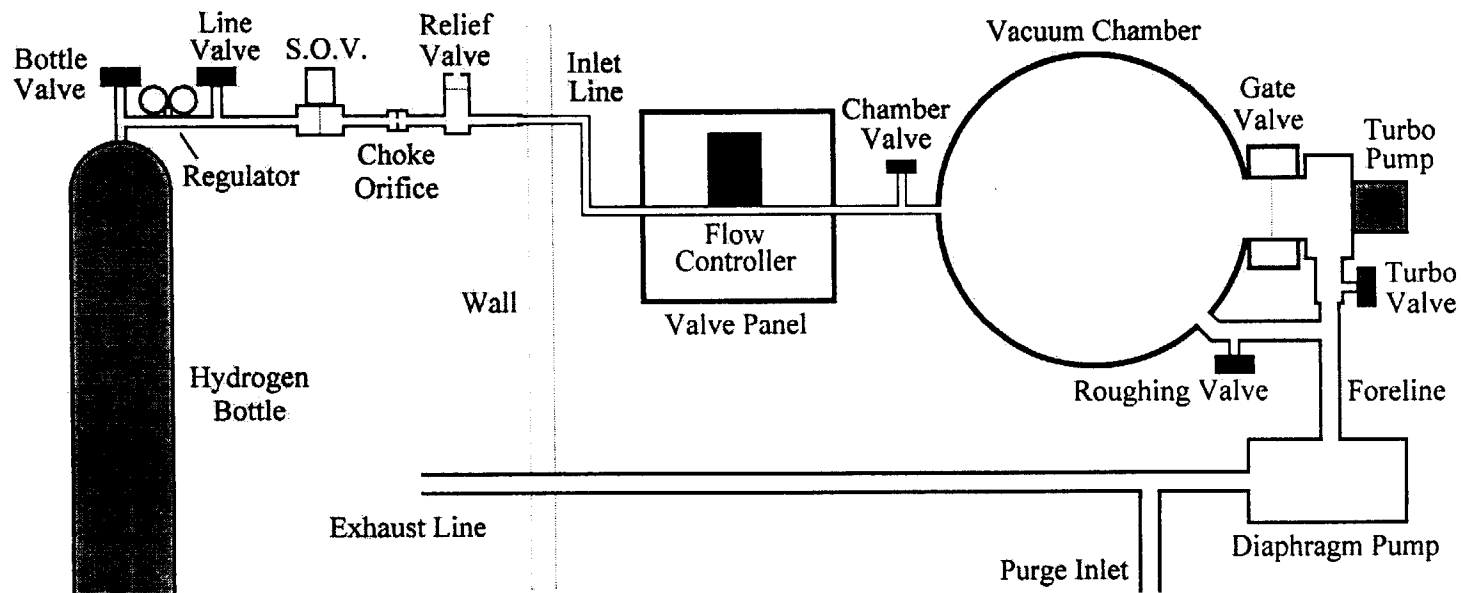
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- * 2-foot, double-wall Spherical Vacuum Chamber
- * 5-kW High Voltage Power Supply by Hipotronics
- * Plasma Diagnostics
 - ❖ Neutron Detector (Ag Counter, He3)
 - ❖ Photon Emission Spectroscopy
 - ❖ Thomson Scattering (under development)
 - ❖ X-Ray Detectors
 - ❖ Microwave Interferometer (near future)
- * Laser Specifications
 - ❖ Pulsed Nd-YAG Laser
 - ❖ 1J/pulse, 10Hz
- * ICCD Gated Camera
- * Propellant Feed System



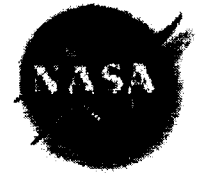
IEC SCHEMATICS

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FUSION AT PRC



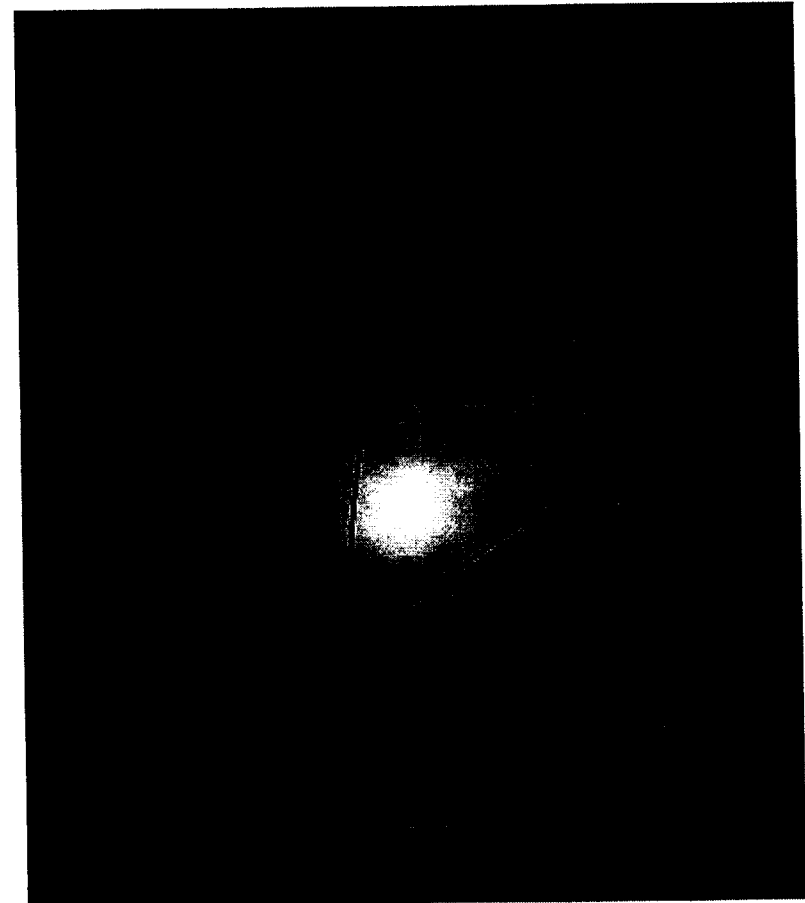
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*** IEC Operation:**

- ❖ Ar, He, N₂ (12-00)
- ❖ Protium (06-01, 01-02)
- ❖ Deuterium (08-01, 01-02)

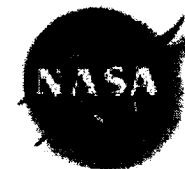
*** Mid August fused Deuterium and generated Neutrons for the first time with PRC's IEC experiment.**

*** Experiment generated a stable, sustainable, continuous and fusible plasma at a variety of power levels and propellant mass flow rates.**

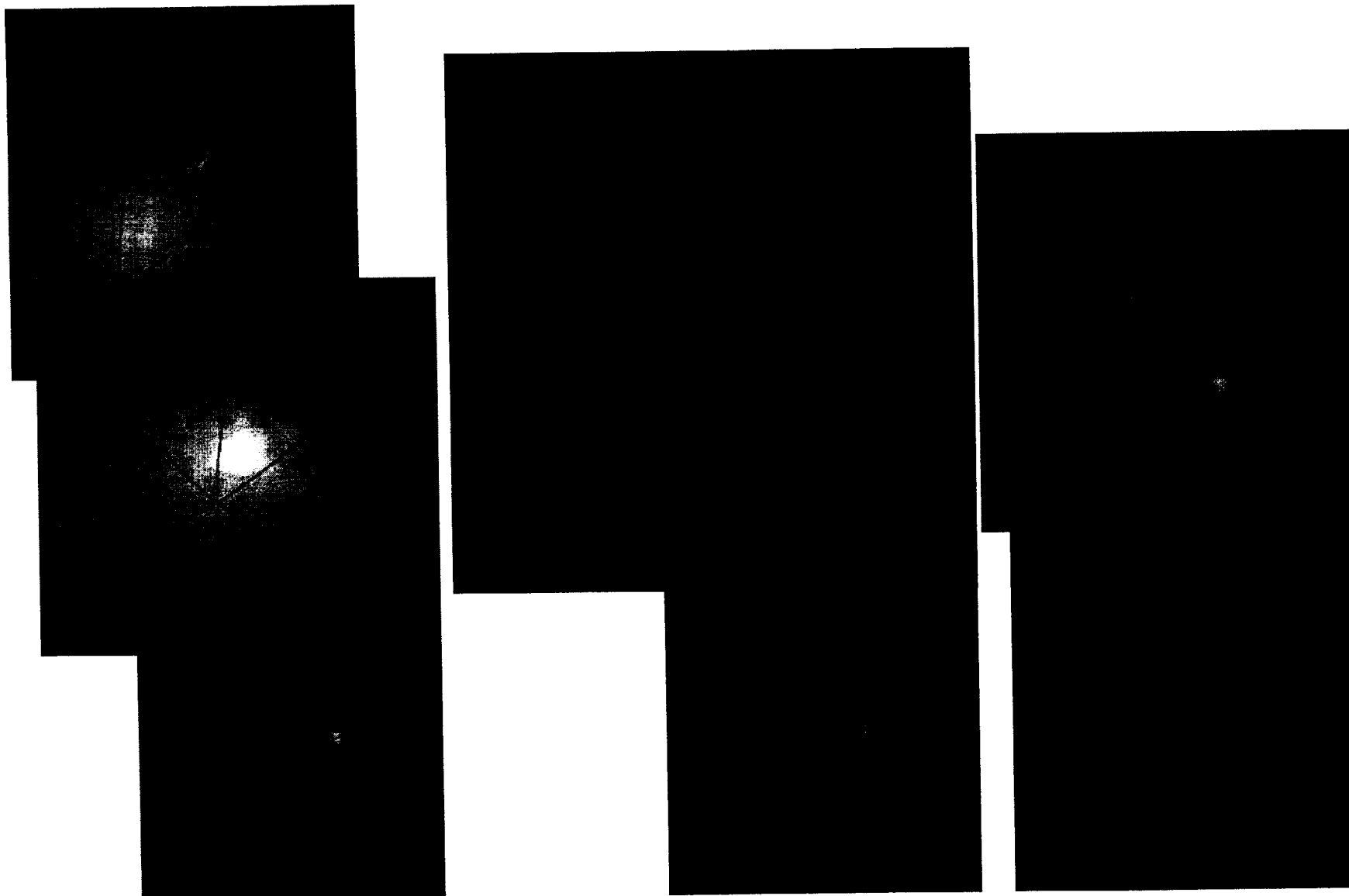




IEC PLASMA IMAGES

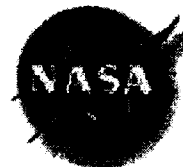


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IEC PLASMA IMAGES

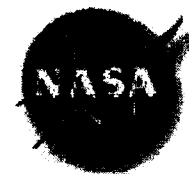


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IEC DEUTERIUM EXPERIMENTS



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Experiment	$p(\text{mT})$	$V(\text{kV})$	$I(\text{mA})$	$P\left(\frac{\text{mA}}{\text{kV}^{3/2}}\right)$	$D(\text{cm})$	$\frac{r_+}{r_-}$	$S(10^6 \text{ n/s})$	$Q(10^{-9})$
Hirsch[3]	0.1	150	10	0.005	18	1.6	50	40
Miley[5]	5	35	3.1	0.015	30	3	0.04	0.43
	10	35	4.1	0.02	30	4	0.05	0.4
	10	35	25	0.12	30	4	0.2	0.27
	20	11	20	0.55	30	4	0.003	0.016
Nebel[6]	0.3	25	20	0.16	56	3.5	10	23
Gu[15]	0.1	60	20	0.04	cylinder	axial	1	1
Ohnishi[16]	12	32	30	0.17	35	6.1	1.5	1.8
[13]		70	15	0.026			1.2	1.3
		10	140^	4.4			0.045	0.04
Thorson[9]	1.9	35	20	0.1	40	8	1	1.7
	1.9	35	20	0.1	40	4	1	1.7
	1.9	58	22	0.05	40	4	5	5
	1.9	20	240	2.7	40	2	1.5	0.37
	1.9	35	20	0.1	40	2	3	5
	1.9	45	20	0.07	40	2	7.5	9.8
Nadler[7]	5	40	15	0.06	61	2.4	1	0.7
	5	40	15	0.06	61	3		
		50	17000^	48	61	2.4	(500)	
		50	17000^	48	61	3	800	1

^Pulsed Experiments

Where is our data?

What
do these
refer to?

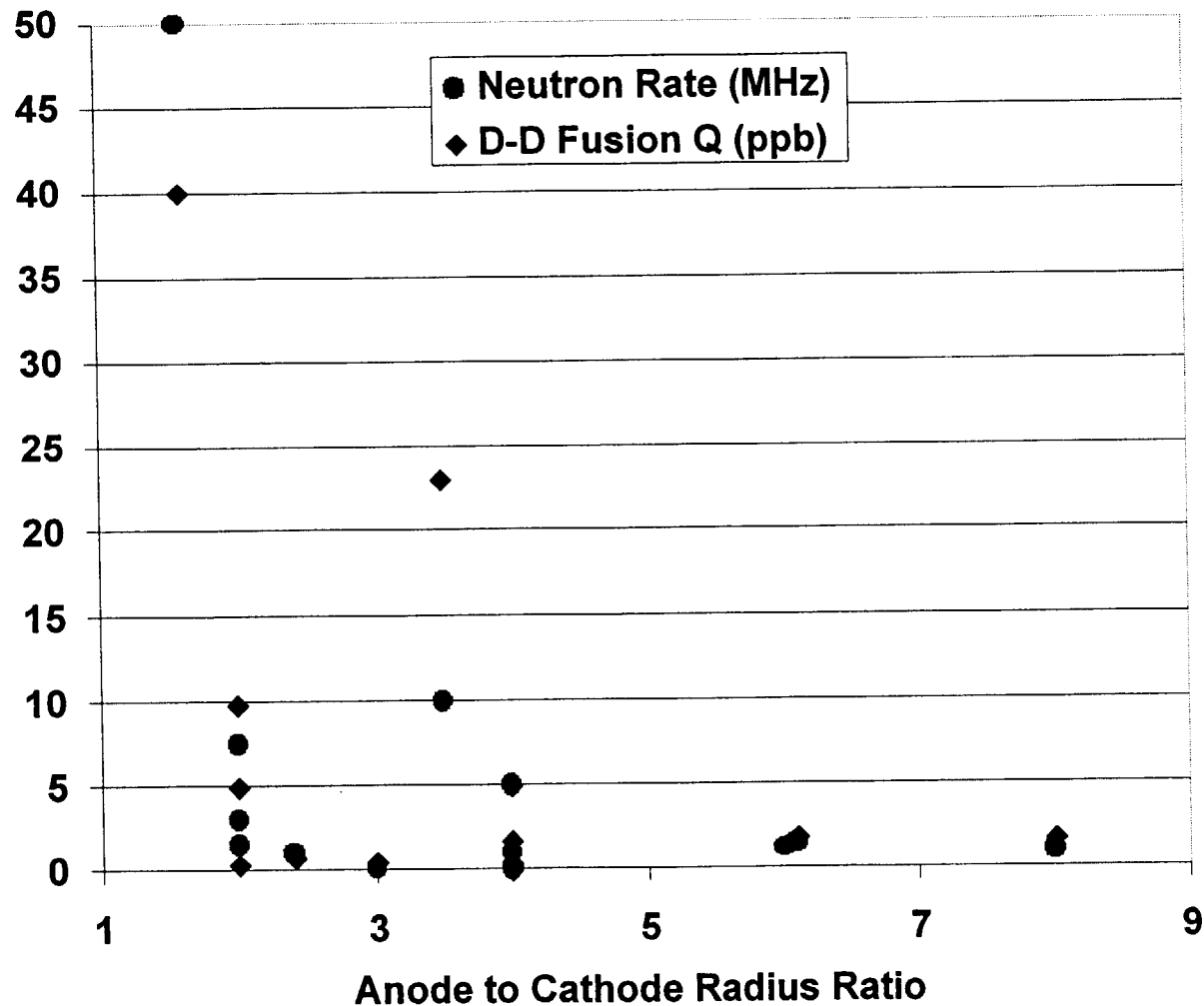


IEC DEUTERIUM EXPERIMENTS



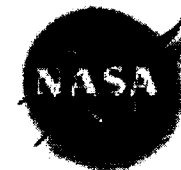
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* Relative Electrode Size and Fusion



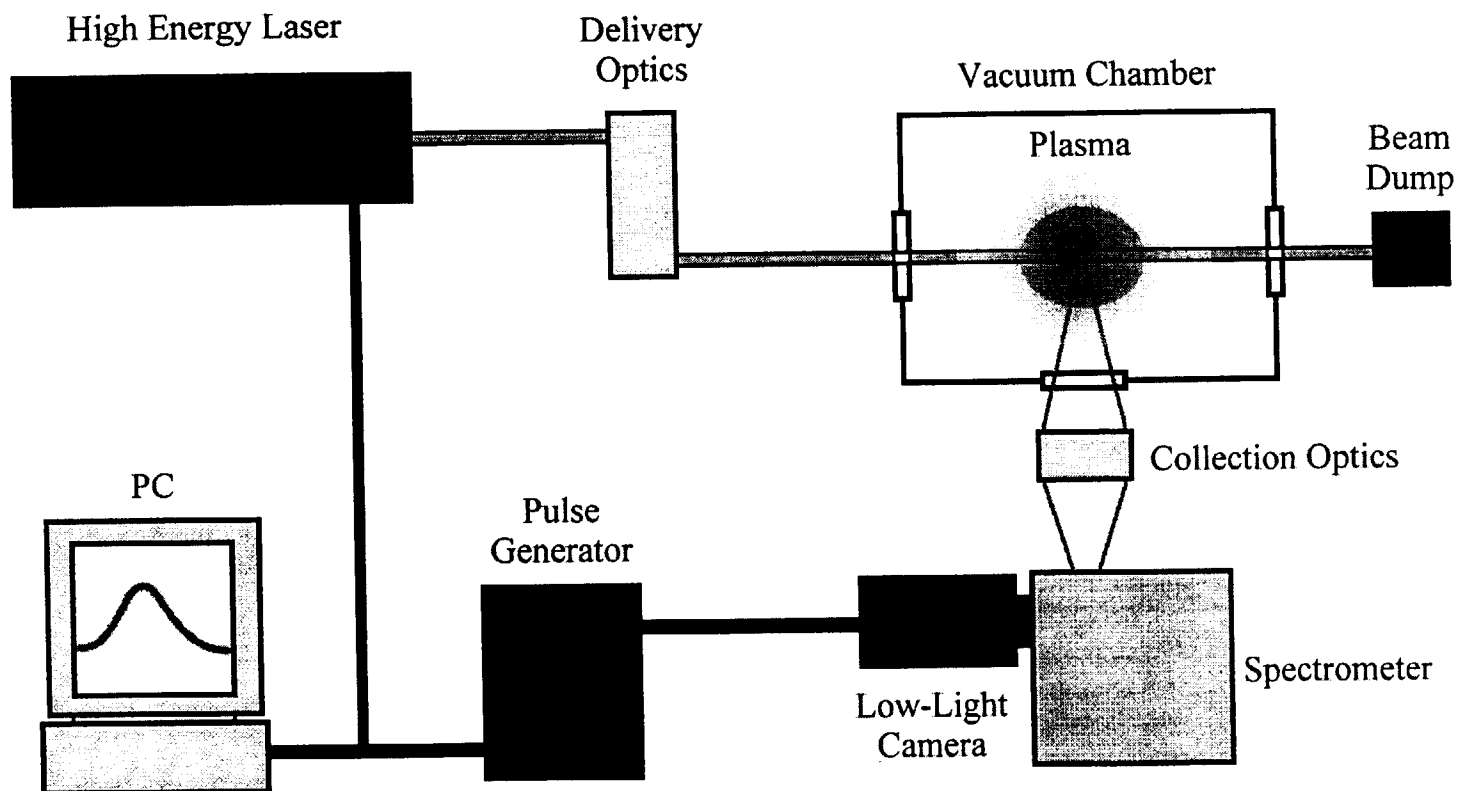


THOMSON SCATTERING



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* Typical Experiment Configuration

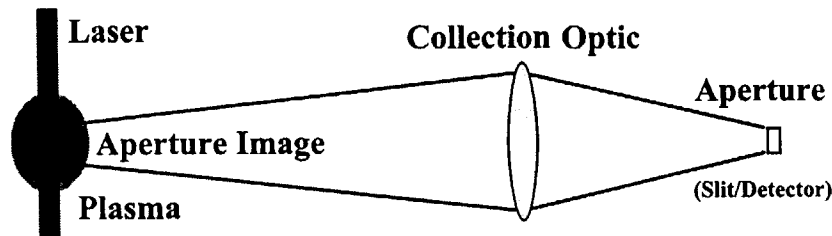


DETECTOR OPTIONS

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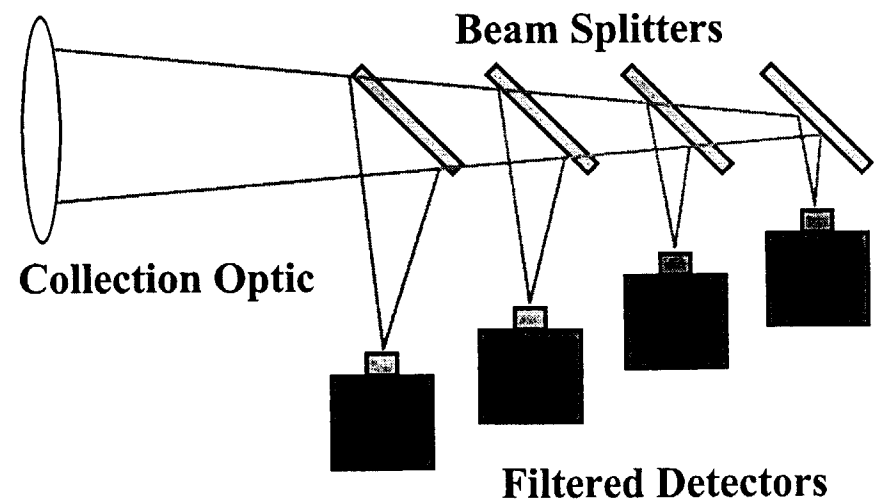
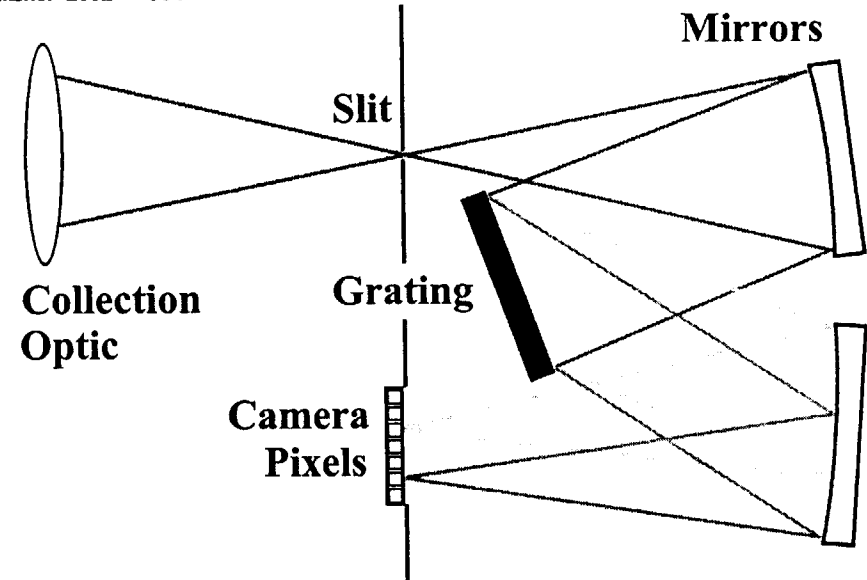
Diffraction Spectrometer and Camera

- ❖ Spatial Information Available
- ❖ Many Wavelength Channels
- ❖ Spectral Flexibility



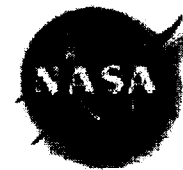
Interference Filters and Photodetectors

- ❖ Mechanically Simple
- ❖ Physically Robust
- ❖ Signal vs. Resolution Flexibility



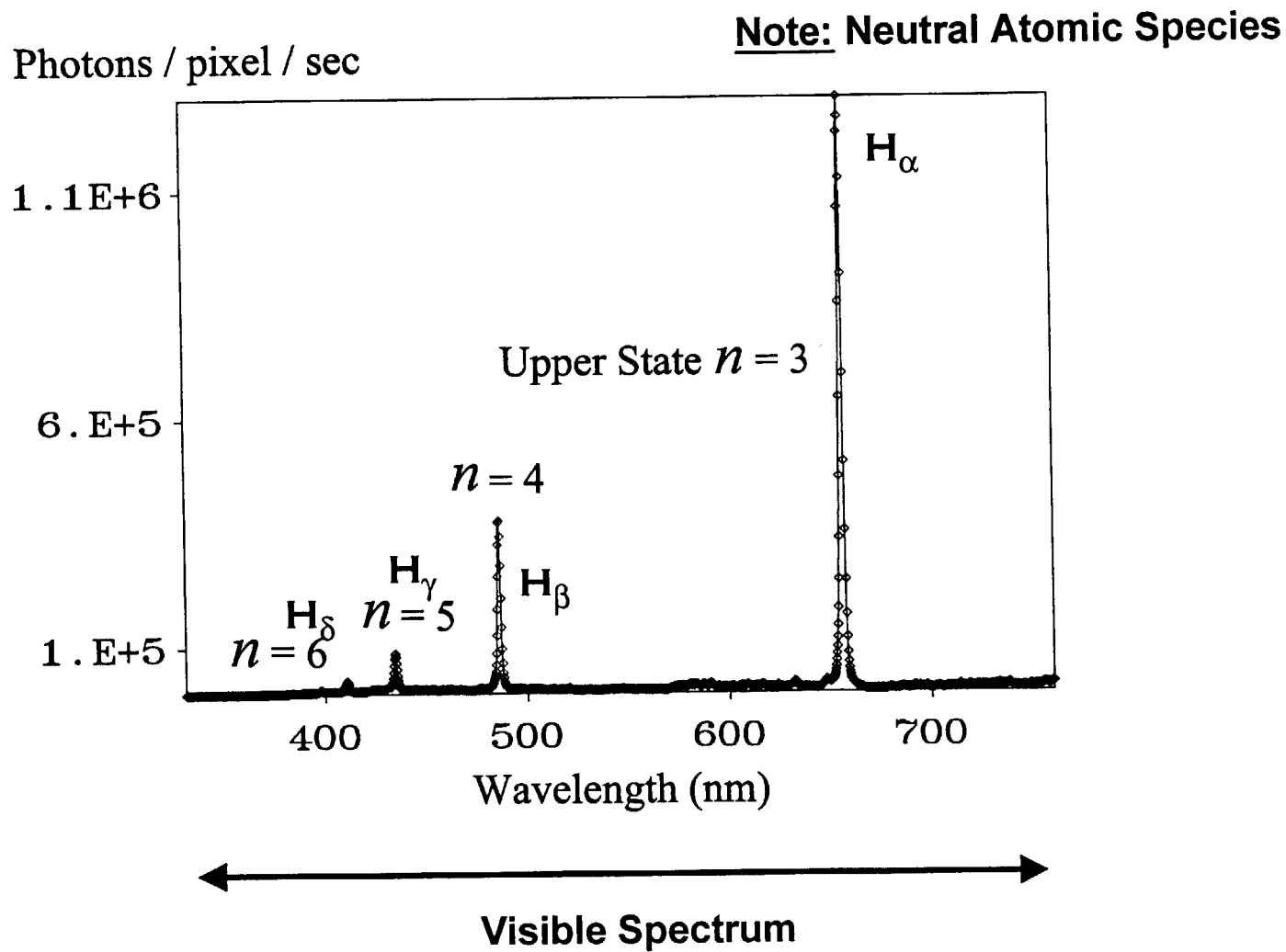


RESULTS



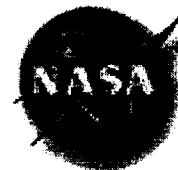
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* Balmer Lines - D2 Plasma



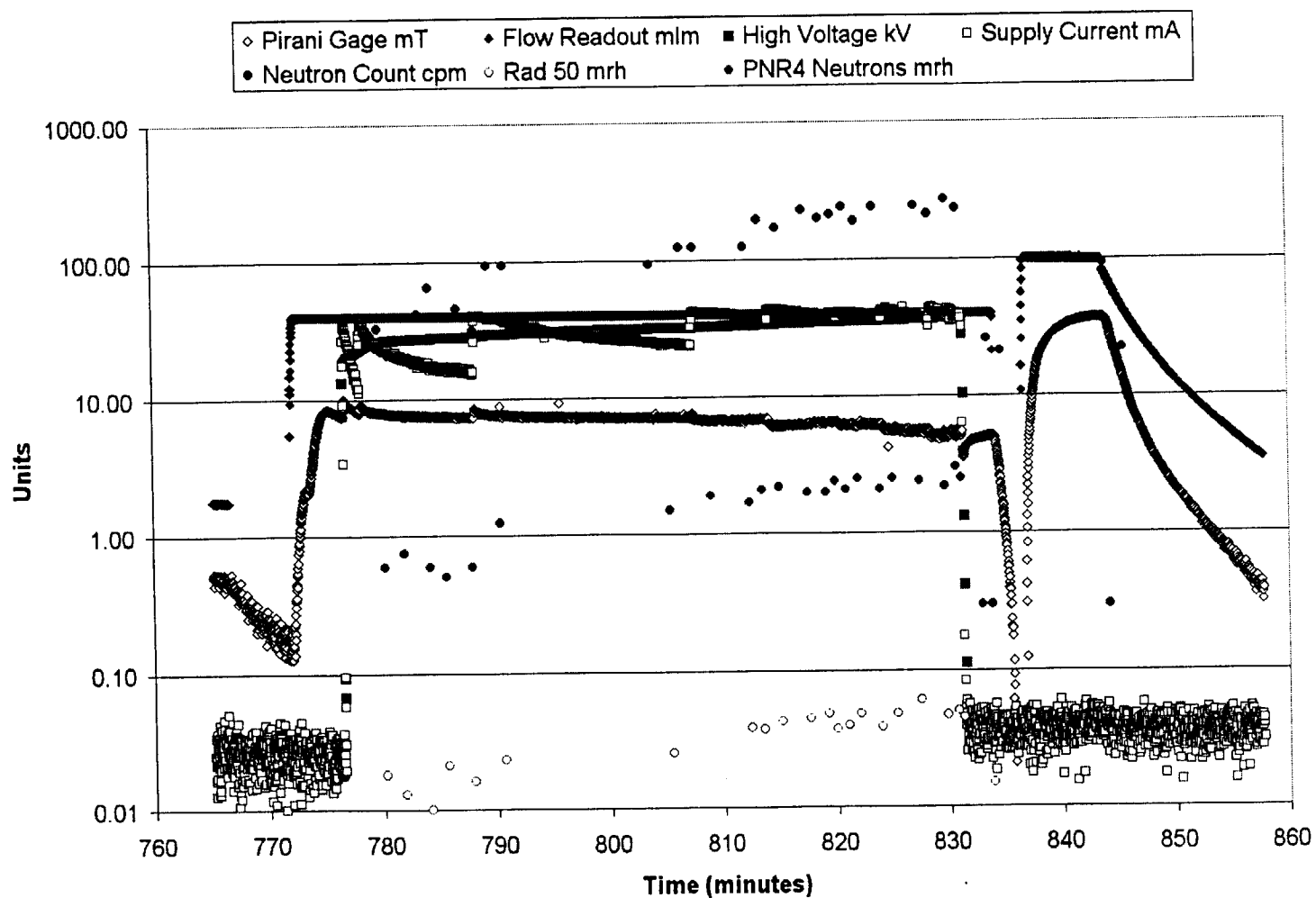


RESULTS



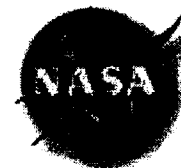
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* IEC Data Set (8-21-01/Deuterium)





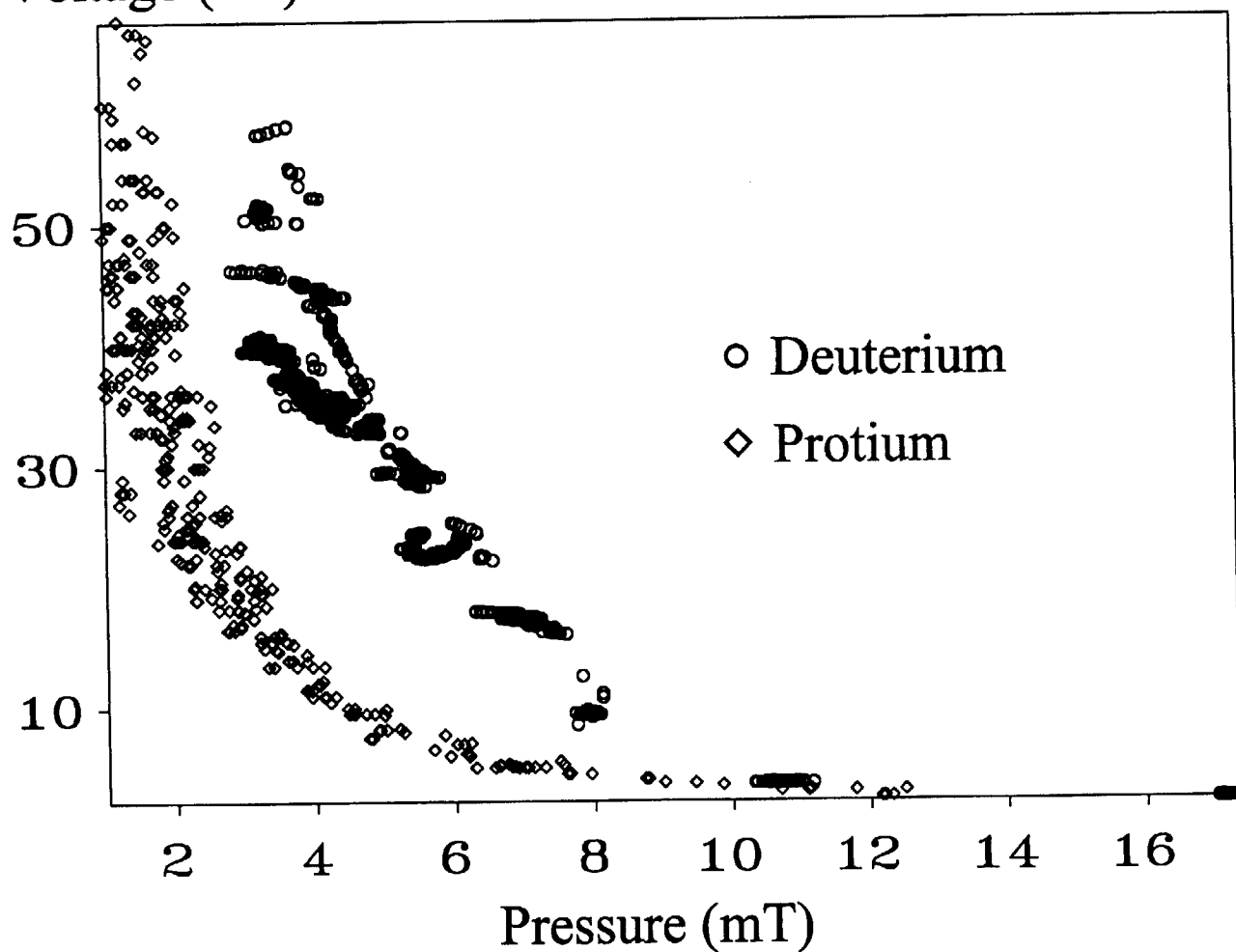
RESULTS



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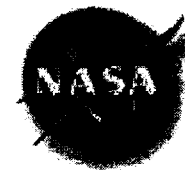
* Paschen Curves for Hydrogen Isotopes in IEC

Voltage (kV)



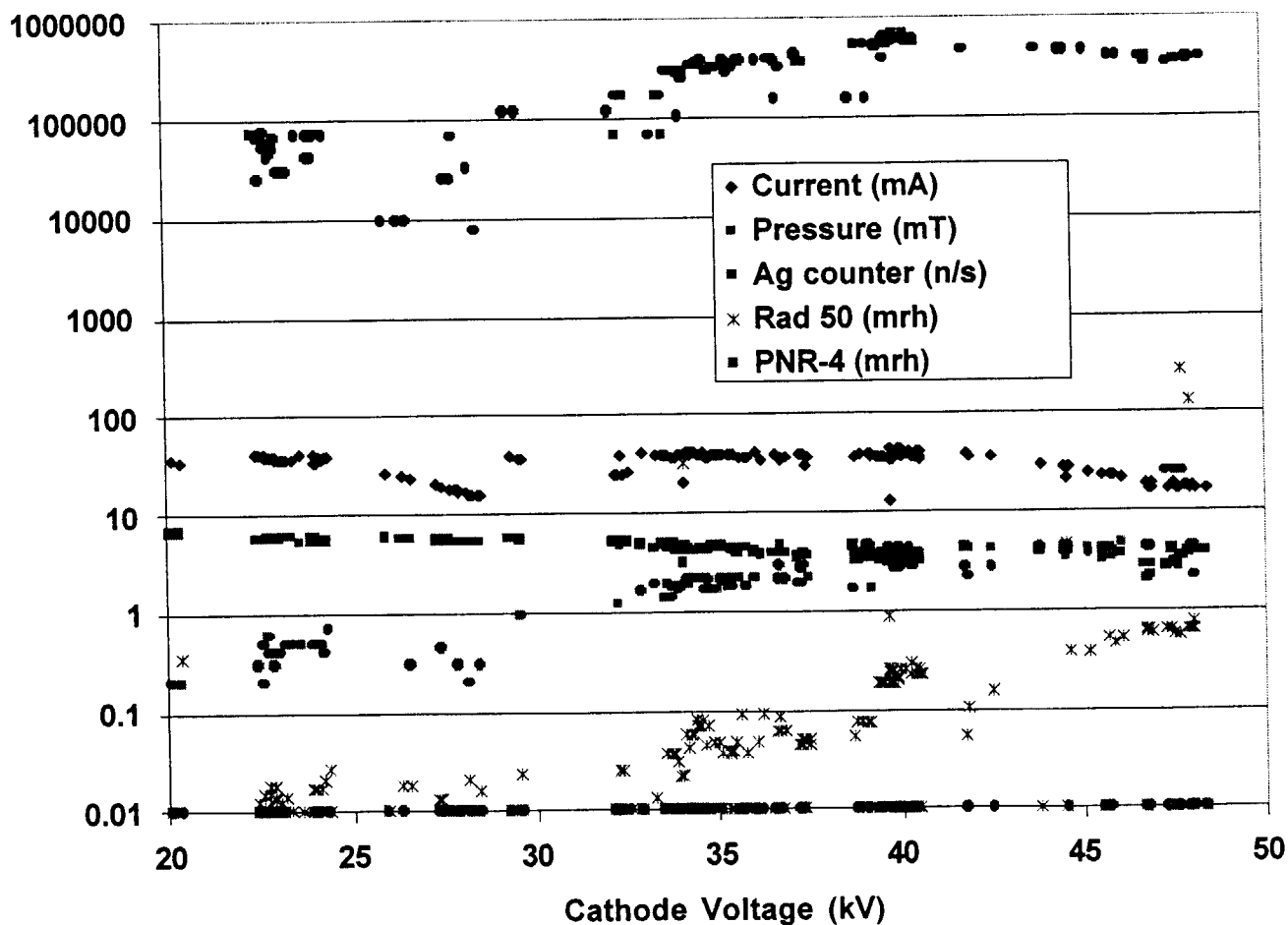


RESULTS



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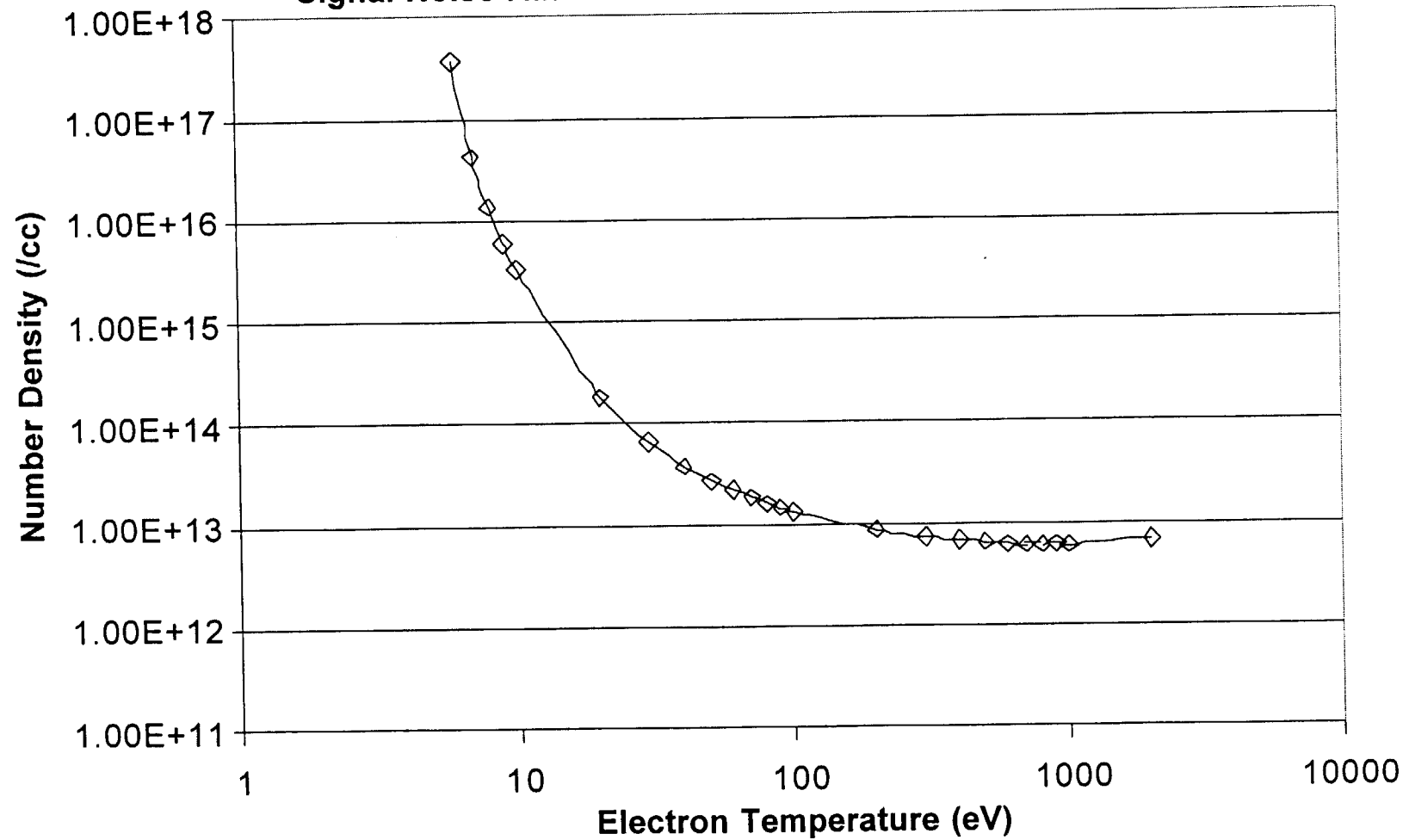
* IEC Radiation Conditions vs. Cathode Voltage



Calculation of Measurable Number Densities vs. Temperature

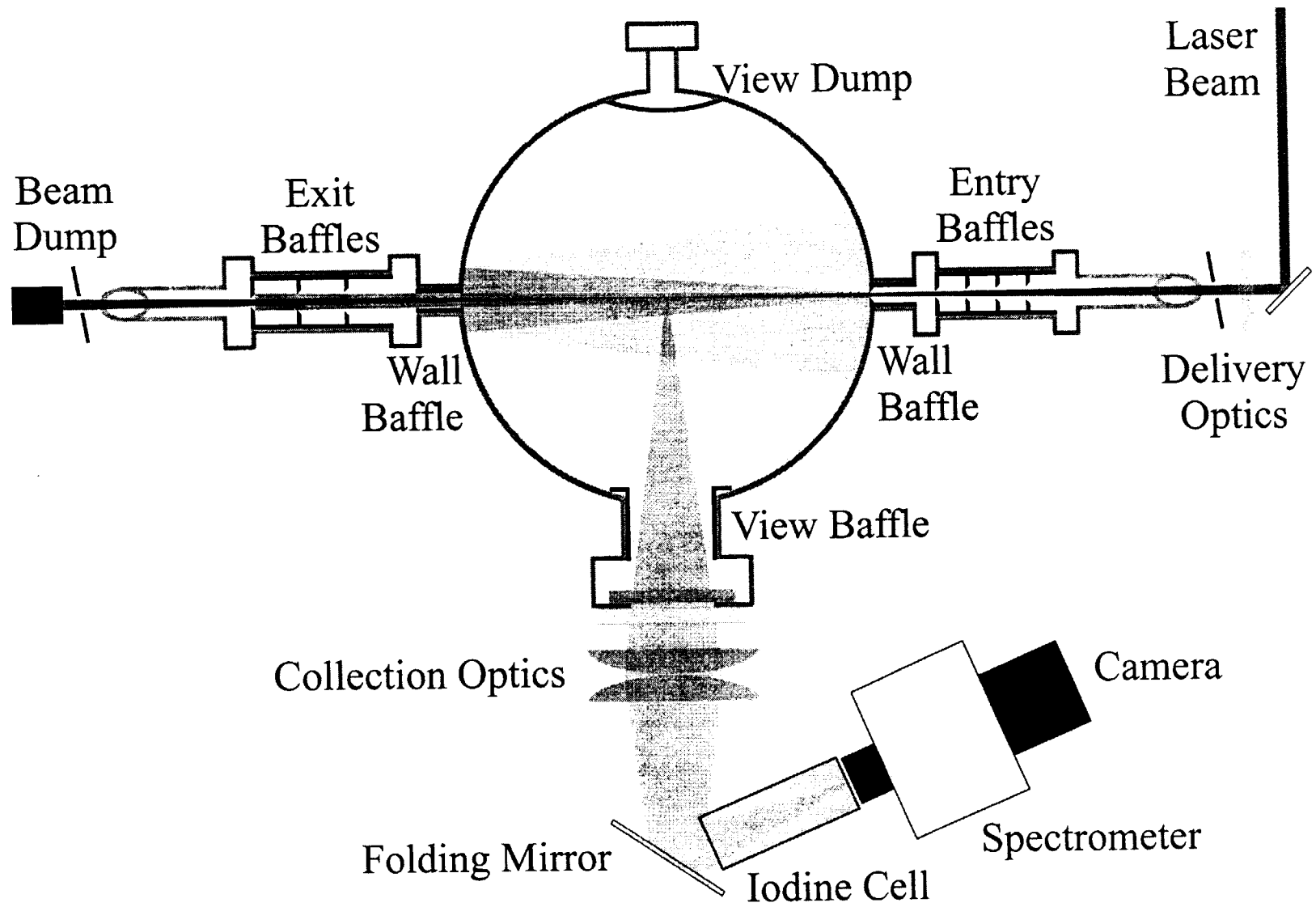
Central Number Density and Temperature Limits from IEC Thomson
Scattering

Signal Noise Ratio = 10 for 8 Minute Measurement ($T = -30^{\circ}\text{C}$)

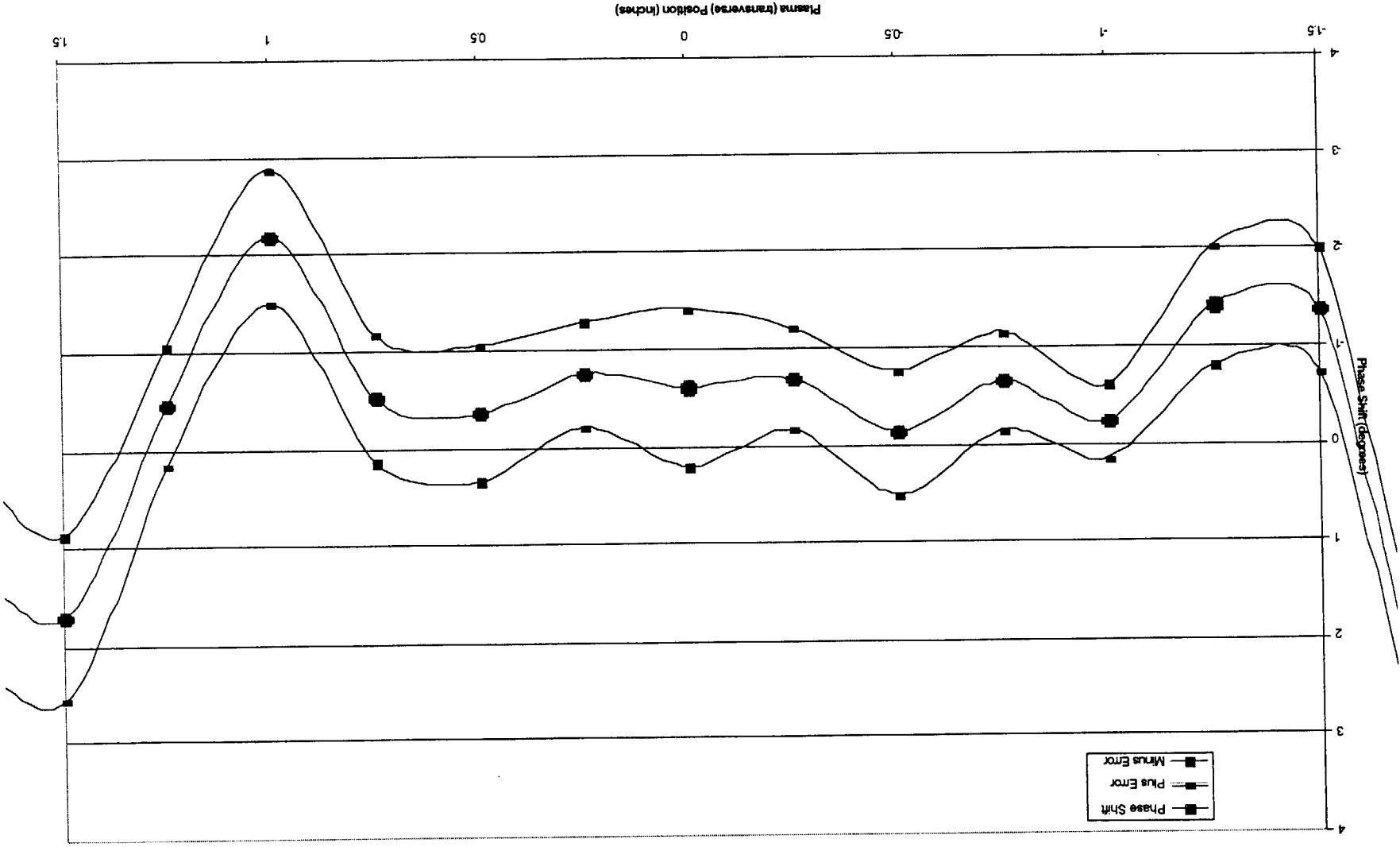


7.6 mT D2, 12 kV.

IEC Stray Light



IEC D2 Interferometric Data (Preliminary)



- Not clear where our data fit in the context of the previous table
- What is the summary of this work?
- Is this a viable precision concept? A looks hopelessly low. Stats going to 1...